C. D. Hornburg

Geothermal Resource Utilization—Paper and Cane Sugar Industries

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INTRODUCTION

This paper was prepared from information developed during a study done by DSS Engineers, Inc., under contract from Lawrence Livermore Laboratory.

The study was made as a specific contribution to an overall report by the United States in the area of industrial utilization of geothermal resources. This is part of an overall study in nonelectrical uses of geothermal resources for a subcommittee of the North Atlantic Treaty Organization.

Due to limited time and funds, it was initially decided to restrict the study to the geopressured zone along the northern Gulf of Mexico Coast. Also, it was to be limited mainly to considering utilizing the thermal energy of this "geoenergy" resource for process use in the pulp and paper industry and cane sugar industry.

For the selected industries and resource area, the final report sets forth energy requirements, identifies specific plant and sites, includes diagrams of main processes used, describes process and equipment modifications required, describes energy-recovery systems, sets forth waste-disposal schemes and problems, and establishes the economics involved.

The scope of work included considerable data collection, analysis and documentation. Detailed technical work was done concerning existing processes and modifications to effectively utilize geothermal energy. A brief survey was made of other industries to determine which of these has a high potential for utilizing geothermal energy.

Presented in this paper is a summary of the findings of the study, with emphasis on how the thermal energy is extracted and utilized in the processes and on the economics involved.

TERMINOLOGY

It is desirable to explain and define certain terms used. There seems to be some confusion as to what to call the energy stored in the earth along the northern Gulf of Mexico Coast. This has been referred to as geothermal energy, as geopressured (or geopressure) energy, and as both. Actually, the greatest quantity of energy the fluid contains is in the form of fuel methane. Thus, we believe it should more correctly and simply be called "geoenergy fluid" (which may even be shortened to "geofluid").

There is also the question of what is energy and how do we measure it in industrial use. The possible answers range from net energy consumption (NEC) to gross energy consumption (GEC), which could include energy used to produce the raw materials absorbed and the capital equipment used.

The NEC, as we have used it, is the actual net thermal heat used, expressed in British thermal units (Btus) plus the electricity consumed, converted to Btus at 3,413 Btu/kilowatt hour (kwhr).

The GEC, as we have used it, is the total gross-energy input to the industry in Btus but excludes energy in raw materials used to produce the product(s) or to produce the capital equipment used. In calculating the GEC, the purchased electricity consumed is converted to Btus at 10,500 Btu/kwhr, which is about the average energy in fuel needed to produce the electricity. The GEC includes

DISCLAIMER

captive energy, i.e., energy obtained from waste products. In the pulp and paper industry and the sugar industry these are hogged wood, bark, spent pulping liquors, and bagasse.

Occassionally it was necessary, for comparison purposes, to omit captive energy and purchased electricity from the amounts stipulated. In these cases we have defined the energy as gross purchased energy and gross purchased fuels. It is important to know which of these are referred to when comparing energy consumption figures.

INDUSTRY REVIEW

Pulp and Paper Industry

The total value of products shipped by industries classified as pulp mills (except building paper) was $7,071 million in 1972. Employment in the total pulp and paper industry is approximately 390,000, and about 30 percent, or 120,000, are employed in the Deep South. The growth of the pulp and paper industry is predicted at 4.2 percent annum through 1980.

We have calculated that the industry's total GEC in 1971 was 2,353 trillion Btus. Of this amount, 1,196 trillion Btus (50.9 percent) was from purchased fuels, 367 trillion Btus (15.6 percent) from purchased electricity, and 790 trillion Btus (33.5 percent) from captive energy (waste products). The sources of energy used by the pulp and paper industry are shown in figure 1.

The gross purchased energy consumed by the pulp and paper industry was 1,563 trillion Btus in 1971, or 9.16 percent of all energy purchased by all industries in the United States. Fuel oil use by pulp and paper in 1971 was 64,588 $\times$ 10^3 barrels, or 26.3 percent of all industrial consumption.

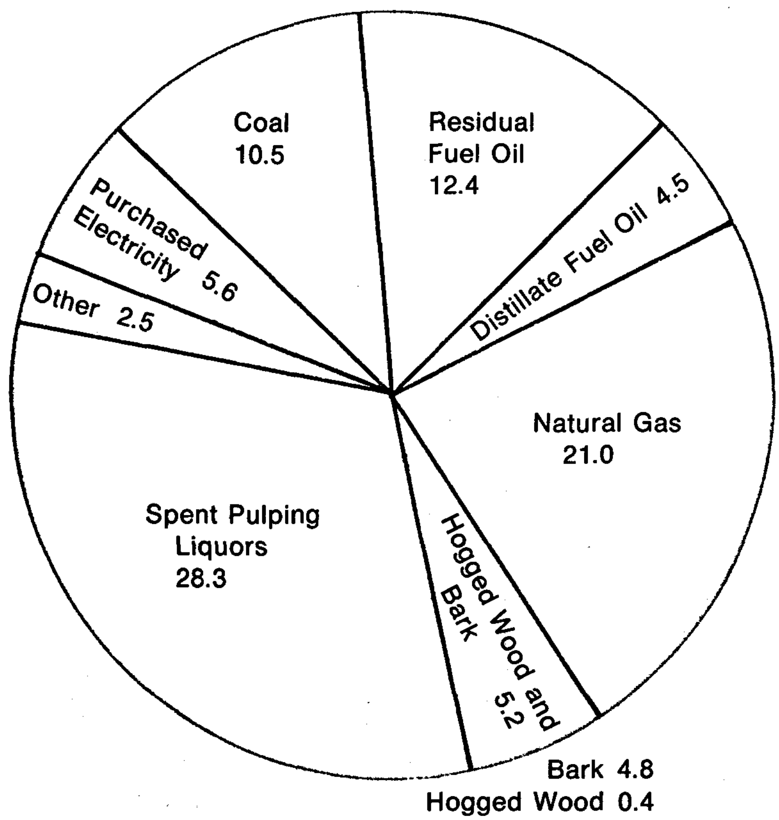


Figure 1. U.S. Pulp and Paper Industry Sources of Energy, 1971, Percentage of total use (after Duke [1974]).

Thirty-eight pulp and paper mills are located in Texas and Louisiana. They consume about 0.89 percent of all fuels purchased by industry in the United States. Their gross energy consumption was 256.6 trillion Btus in 1973. Eleven mills in Texas and Louisiana, located in the geoenergy-resource area have a gross energy consumption of about 78 trillion Btus per year.

Cane Sugar Industry

The value of products shipped by the cane sugar industry (raw and refined) was $2,166 million in 1972. Employment was 18,400. There are a total of about 80 companies in this industry, and 20 of these are large firms. The growth of the industry is predicted at 2 percent per annum through 1980.

The total gross energy consumption by the cane sugar industry was 90.01 trillion Btus in 1971. Of this amount, 48.12 trillion Btus (53.4 percent) was from purchased fuels, 1.26 trillion Btus (1.4 percent) was from purchased electricity, and 40.69 trillion Btus (45.2 percent) was from bagasse.

The gross purchased energy consumed by the cane sugar industry was 49.4 trillion Btus in 1971, or 0.29 percent of all energy purchased by all industries in the United States.

There are 43 raw sugar mills and 6 sugar refineries in Louisiana. These consumed 26.6 trillion Btus of gross energy in 1973. Of this, the 6 refineries consumed 12.7 trillion Btus.

Specific Plants and Sites

PULP AND PAPER MILLS. A total of 38 pulp and paper mills are located in Texas and Louisiana. Eighteen are in Texas and 20 are in Louisiana. The locations of these mills are shown on the maps in figures 2 and 3. Eleven of these mills are located within the geoenergy-resource zone. These produce about 400,000 tons per year of market pulp and 1,700,000 tons per year of paper products. They consume a total of 78 trillion Btus of gross energy. Detailed energy-use data was obtained on two of the plants within this area. These are the Boise-Southern Company mill at DeRidder, Louisiana, and the Celotex Corporation mill at Marrero, Louisiana. A summary of this information follows.

BOISE-SOUTHERN COMPANY

Purchased Fuels—	5.65×10^{12} Btus
Captive Fuels—	7.96×10^{12} Btus
Purchased Electricity—	3.61×10^{12} Btus
TOTAL GEC =	17.23 trillion Btus

Energy: Product Ratio = 17,858 Btus/pound
Purchased Fuel Cost = $2,401,565 = 42.50¢/$10^6$ Btus
Electricity Cost = $2,598,683 = 0.756¢/kwhr

CELOTEX CORPORATION

Purchased Fuels—	2.217×10^{12} Btus
Captive Fuels—	— — — — — — —
Purchased Electricity—	0.949×10^{12} Btus
TOTAL GEC =	3.166 trillion Btus

Energy: Product Ratio = 13,900 Btus/pound
Purchased Fuel Cost = 52.1¢/10^6 Btus
Electricity Cost = 0.89¢/kwhr

By the end of 1974 the purchased fuel and electricity cost for both these mills was about $1.00 per million Btu and 1.5¢/kwhr.

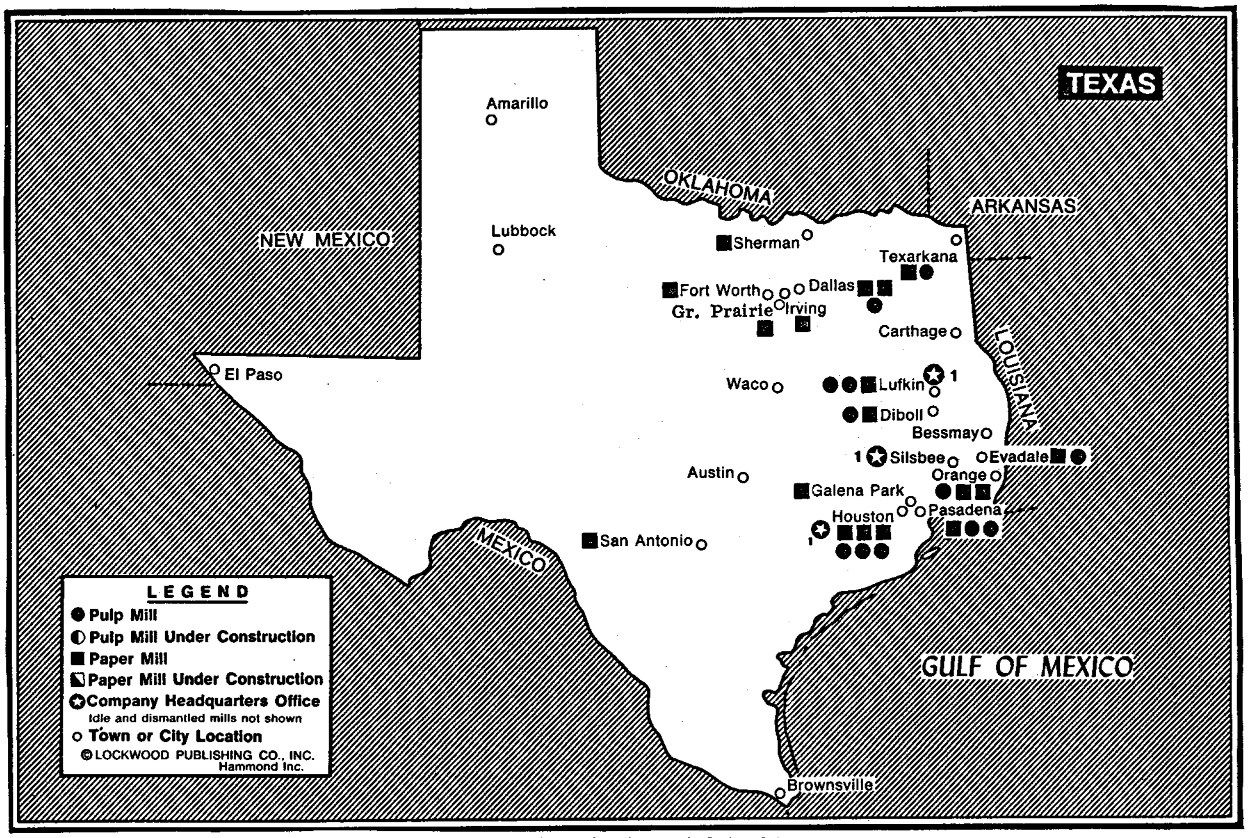


Figure 2. Location of Pulp and Paper Mills in Texas (from Lockwood [1974] by permission).

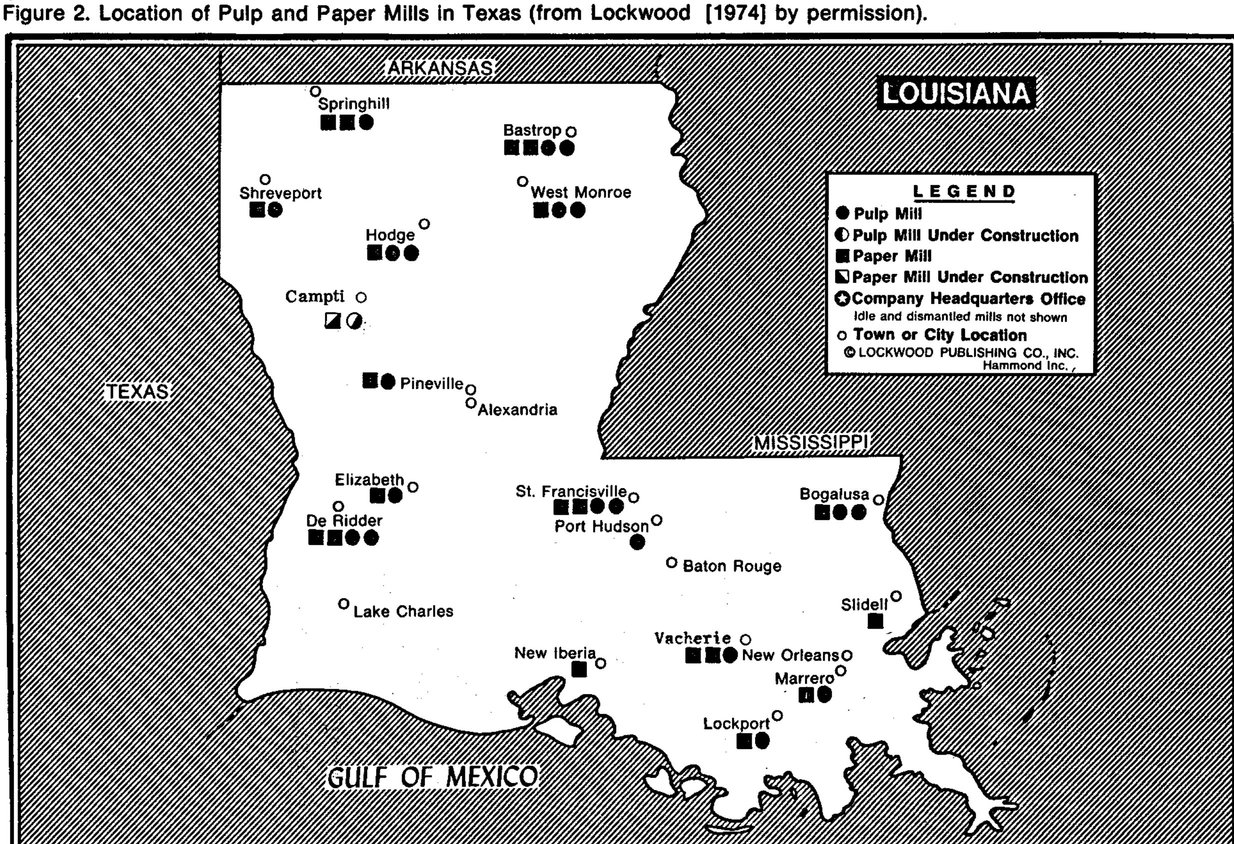


Figure 3. Location of Pulp and Paper Mills in Louisiana (from Lockwood [1974] by permission).

RAW SUGAR MILLS AND SUGAR REFINERIES. In Louisiana there are a total of 43 raw sugar mills and 6 sugar refineries. Three of these refineries are integrated with raw sugar mills. There is only one sugar refinery in Texas; this is at Sugarland, Texas. The 43 raw sugar mills are scattered throughout the sugar cane growing area in Southern Louisiana. The location of the 6 refineries are shown on the map in figure 4. These 6 refineries produce 1,650,600 tons per year of refined sugar, or about 22 percent of the total U.S. production.

As noted previously, the raw sugar mills and sugar refineries use about 26.6 trillion Btus per year of gross energy. The average consumption of the raw sugar mills is 325,000 $\times$ 10^6 Btus each, while the sugar refineries use from 1 trillion Btus per year to 3.8 trillion Btus per year (Amstar Plant at Chalmette). The South Coast Refinery at Houma was selected for detailed study. This is an integrated mill but does not burn bagasse. The bagasse is dried and sold to make building board.

SITES FOR NEW PLANTS. From the energy-supply standpoint, it would be desireable to locate new plants at a site where high energy-containing fluid could be obtained at minimum depths. However, the lack of specific, detailed information on the nature and extent of the geoenergy resource made site selection on this basis almost impossible. Therefore, we concerned ourselves with finding a site within the geoenergy zone that would satisfactorily meet the other needs of these industries. The area recommended is southwestern Louisiana, in the vicinity of Lake Charles and Port Arthur. That area is characterized by heavy industries, and many of the raw materials required by these industries abound there. Within this 15-parish corner of the state grows an estimated 6,000,000 cords of softwood and 10,750,000 cords of hardwood

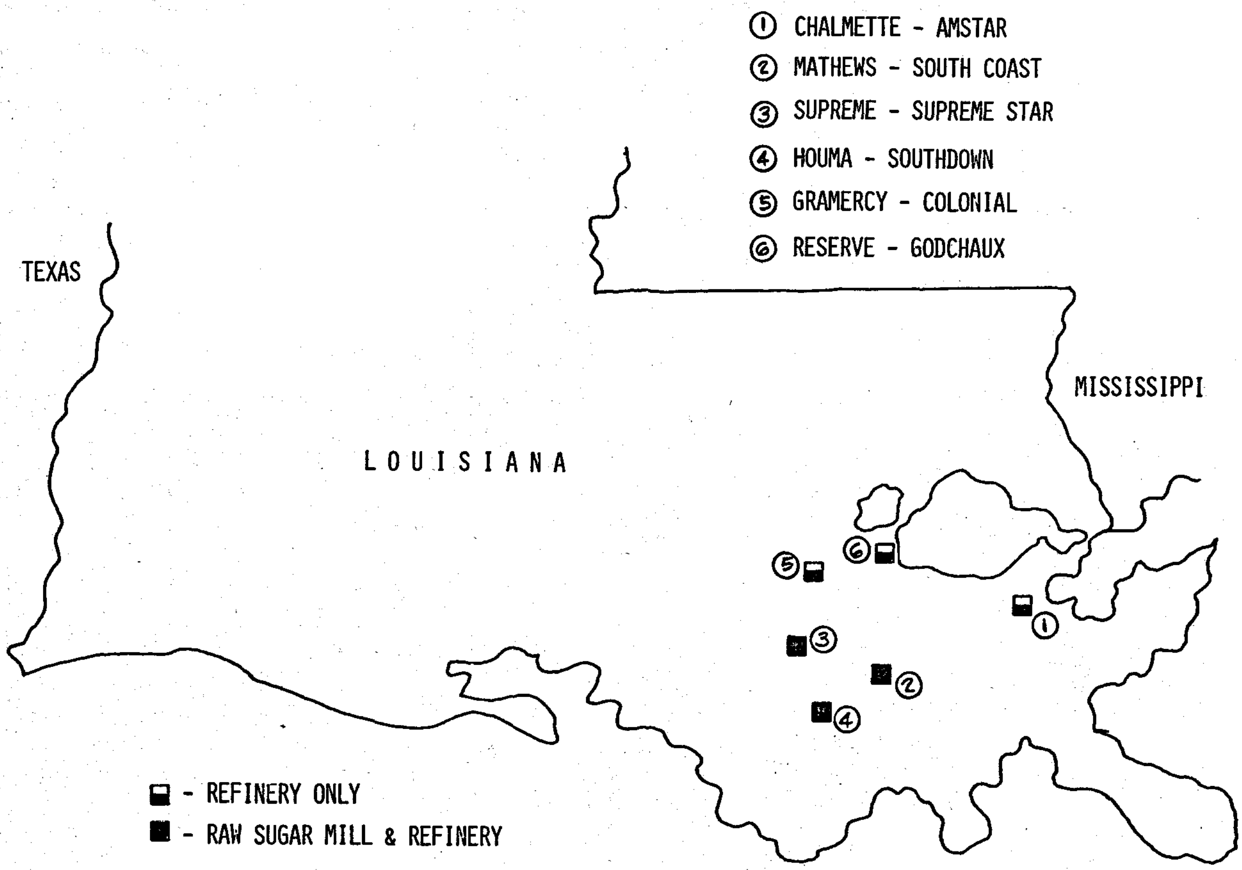


Figure 4. Location of Sugar Refineries in Louisiana.

timber. Good transportation—an essential—is available in this area, including deep-water ports.

OTHER INDUSTRIES. A brief survey was made to determine what other industries or processes have potential for economical utilization of the thermal energy in the geoenergy fluid. The six highest energy-consuming industries are: food and kindred products; paper and allied products; chemicals and allied products; petroleum and coal products; stone, clay and glass products; and primary metal industries. In 1971, these accounted for 76 percent of all purchased gross energy used in industry. Plants classified in these industries and located in Texas and Louisiana consumed 20.7 percent of the purchased industrial energy.

About 2,955 trillion Btus per year of gross energy is used in petroleum refining and 26 percent of this is used as low-level heat from low-pressure-process steam. Most of this low-level heat is used for vacuum distillation, lube oil refining, and wax refining. A large portion of this could be supplied by 250°F to 300°F geothermal fluids. We calculate the potential utilization of geothermal energy for petroleum refining in Texas and Louisiana at 390 trillion Btus.

Analysis of the processes used in the industrial organic chemicals group showed that acetic acid, acetic anhydride, ethyl alcohol, and isopropyl alcohol can be produced with almost all the energy needed being supplied by low-level geothermal. This could amount to 30.5 trillion Btus for production in Texas and Louisiana by 1980.

Similar analysis of the industrial inorganic chemicals group revealed that sulfur, bromine, aluminum sulfate, and alums could be produced with energy supplied by low-level geothermal sources. This was estimated at 60 trillion Btus per year, with 40 trillion Btus per year for sulfur extraction alone.

Additionally, it was found that large quantities of low-level heat are used to concentrate sodium hydroxide, which is produced concurrently with chlorine. It was estimated that 24 trillion Btus of this could be supplied by low-level geothermal in the Gulf Coast region by 1980.

GEOTHERMAL RESOURCE DATA AND RECOVERY SYSTEMS

Location

Exact data on the nature and extent of the geoenergy resource are lacking, and there is a great need for actual reservoir-performance data. Published data indicate that the geoenergy resource area extends along the landward margin of the Gulf of Mexico Coast from the Rio Grande to the vicinity of the Mississippi River.

Characteristics

Characteristics of the geoenergy fluid include: 180°F to 350°F, 500 psi to 3,000 psi, and 0 to 50 standard cubic foot (scf) gas/barrel (bbl). These characteristics are obtainable from wells 8,500 feet to 18,000 feet deep. The flow rates from the wells are estimated at from 20,000 to 80,000 barrels per day (bpd) per well, with a maximum estimated withdrawal rate of 171,200 barrels per day from a single reservoir at 292 days per year for 20 years. The expected average characteristics of geoenergy fluid from wells of various depths is shown in figure 5.

The basic system for recovery of the geoenergy is shown in figure 6. This consists of supply wells, strainers, high-pressure gas separators, hydraulic turbines with generators, a low-pressure gas separator, and thermal-recovery equipment. The technology for the design of this system and its equipment is simple, and it can presently be constructed. This system will recover natural gas and thermal energy and generate electricity from pressure energy. Possible additional benefits can be found in utilizing a Rankine cycle for power

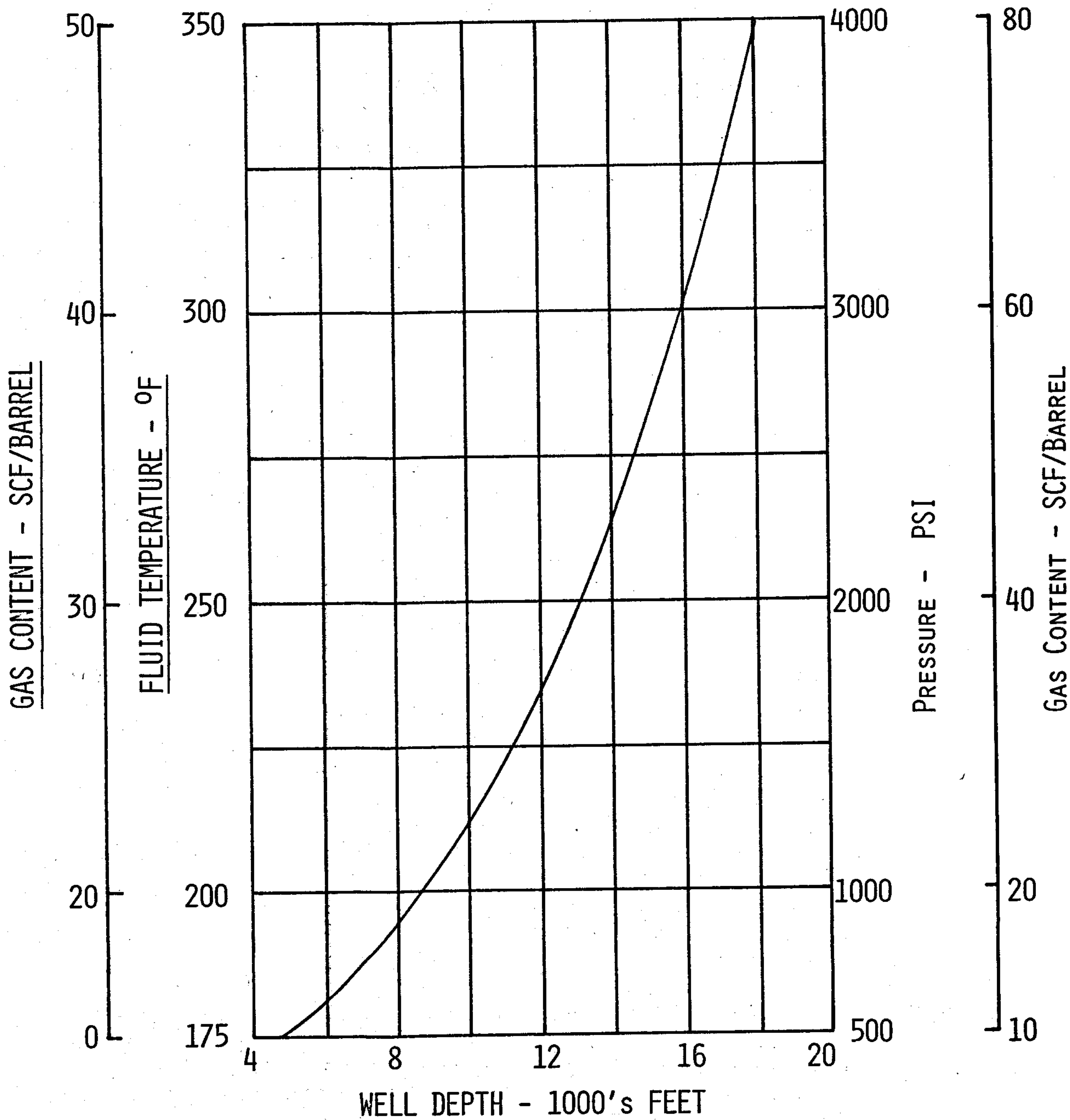


Figure 5. Geofluid depth (Based on Johnson and Towse [1974]).

generation and producing purified water. These were not investigated in detail since they would complicate the systems employed.

The simplest and most efficient method of extracting heat from a geothermal fluid for process use is by liquid-liquid exchange. However, for the cases studied, it was found that this can be done to provide all the fluid for process use only in the new raw sugar mills and new sugar refineries. For other cases studied, part or all of the heat has to be obtained by flashing down the geothermal fluid to produce steam.

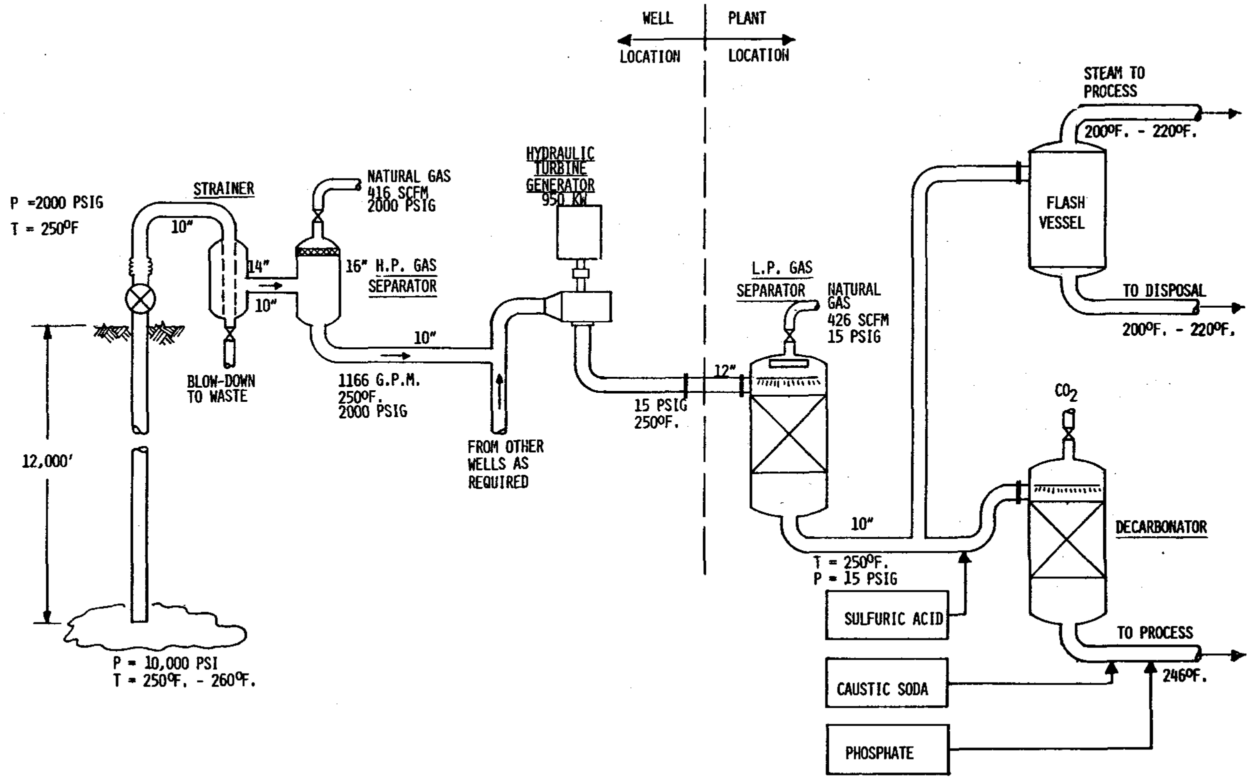


Figure 6. Basic Energy Recovery System

WASTE DISPOSAL

The most technically sound and environmentally safe method of disposing of the spent geoenergy fluid is by injecting it back into the ground strata. Althought cost of this disposal method is quite expensive, it appears to be less expensive than alternate methods in most locations.

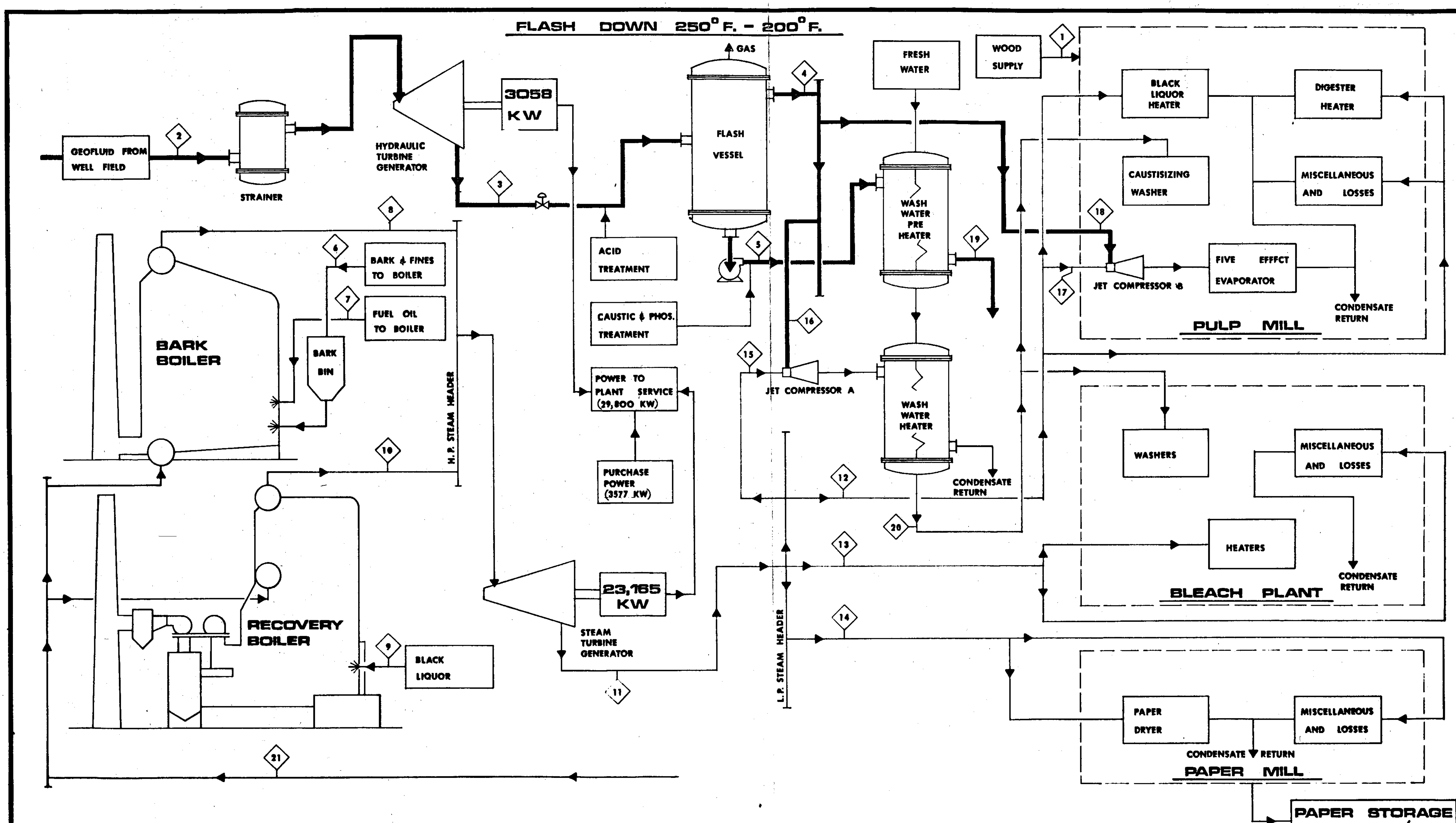
The geoenergy area of consideration contains many geologically suitable sites for fluid injection into the ground. On the average, a 3,000-foot deep disposal well could handle 400 gallons per minute (gpm) of fluid with an injection pressure of 200 psi. Surface equipment consisting of storage tank(s), settling ponds, filters, and pumps would be required.

Thermal Process Use in Pulp and Paper Mills

The utilization of geothermal energy in pulp and paper making was investigated by detailed analysis of a typical 1,000-ton-per-day bleached paper plant using the Kraft process. Heat and material balances were developed to show energy savings and use in a typical existing plant, and in both a new and an actual existing plant designed to use geothermal.

The typical plant without geothermal requires a gross energy input of 1827 × 10 Btus/hr or 12.8 trillion Btus per year. This is supplied from 595,634 barrels of fuel oil and 219,000 tons bark plus black liquor recovery.

The energy-system diagram for the existing typical pulp and paper mill using geothermal is shown in figure 7. Modifications to use geothermal in this typical existing mill consist of adding a flash vessel, deleting existing hot-water wash heaters, adding new wash-water heaters, and adding jet compressors. These modifications make it possible to use geothermal heat and reduce the gross energy needed from fuel and purchased electricity by 15.56 percent. This represents a fuel-oil savings of 394,697 barrels per year, but purchased electricity is required, which may be generated from the fluid-pressure energy.



MATERIAL BALANCE

PROCESS STREAM NUMBERS

	WOOD TO BARKING DRUM	GEOFLUID FROM WELL FIELD	GEOFLUID HYDRAULIC TURBINE OUTLET	VAPOR FROM FLASH VESSEL	BRINE FROM FLASH VESSEL	BARK & FINES TO BOILER	FUEL OIL TO BARK BOILER	H.P. STEAM FROM BARK BOILER	BLACK LIQUOR TO RECOVERY BOILER	H.P. STEAM FROM RECOVERY BOILER	L.P. STEAM FROM TURBINE GENERATOR
	1	2	3	4	5	6	7	8	9	10	11
FLOW (#/HR x10³)	247.67	2003.32	2003.32	95.15	1908.17	62.50	9.744	266.544	246.79	461.58	728.124
TEMPERATURE (°F)	AMB.	250	246	200	200	AMB.	AMB.	700	—	700	420
PRESSURE (PSIA)	—	2014.7	29.83	11.53	—			450	—	450	136
ENTHALPY (BTU/#)	—	222.87	214.42	1145.9	167.99			1359.9	—	1359.9	1232.9
						4750 (HHV)	18,500 (HHV)	—	4035 (HHV)	—	

	L.P. STEAM TO PULP MILL	L.P. STEAM TO BLEACH PLANT	L.P. STEAM TO PAPER MILL	L.P. STEAM TO JET A	VAPOR TO JET A	L.P. STEAM TO JET B	VAPOR TO JET B	BRINE FROM PRE-HEATER	HOT WATER FROM WASH HEATER	CONDENSATE RETURN	
	12	13	14	15	16	17	18	19	20	21	
FLOW (#/HR x10³)	290.206	18.466	356.35	63.107	62.059	82.72	33.09	1908.17	2192.17	728.124	
TEMPERATURE (°F)	420	420	420	420	200	420	200	135	212	312	
PRESSURE (PSIA)	136	136	136	136	11.53	136	11.53		—	500	
ENTHALPY (BTU/#)	1232.9	1232.9	1232.9	1232.9	1145.9	1232.9	1232.9	102.9	180.07	281.2	

DSS ENGINEERS, Inc.
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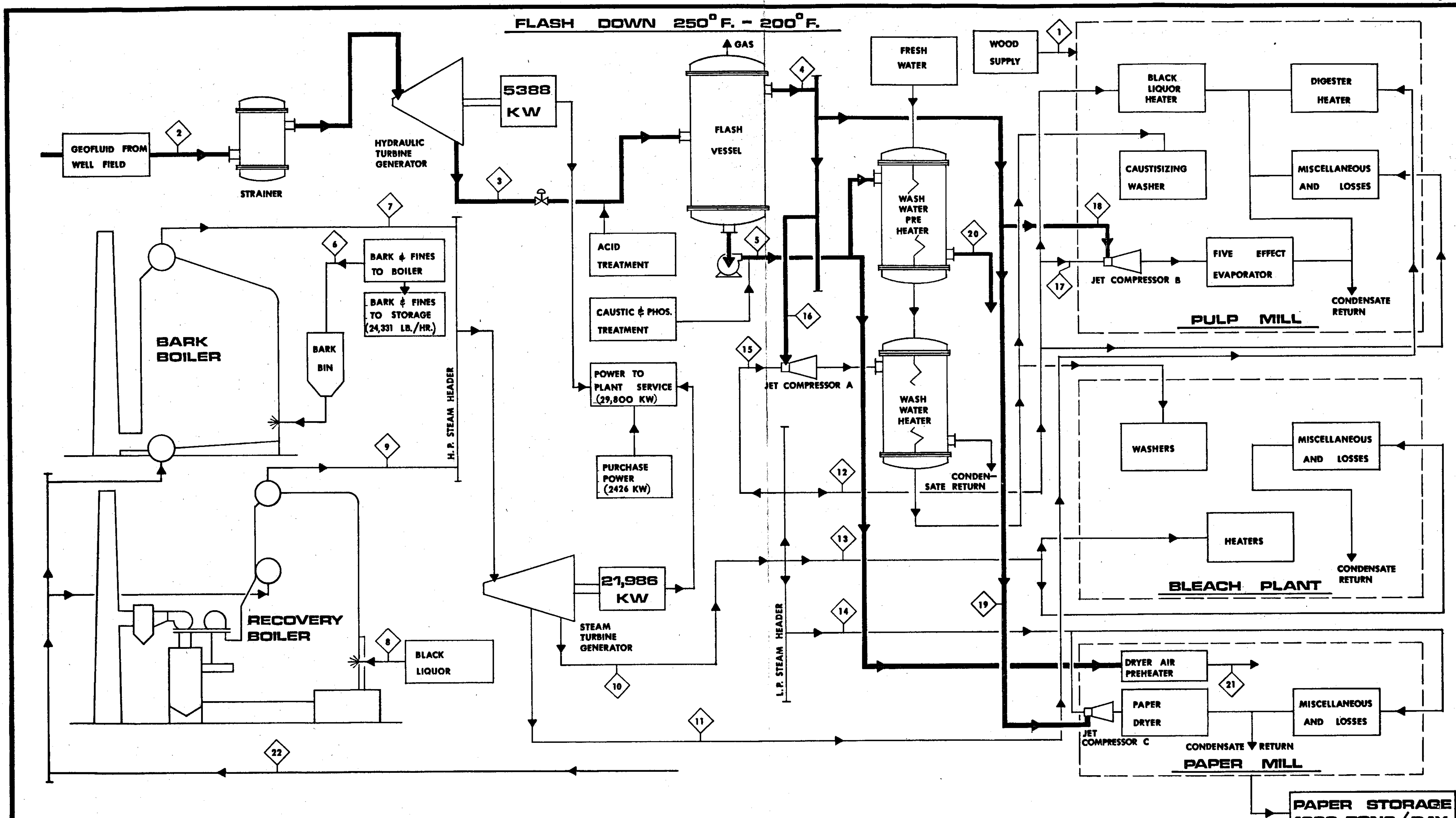
APPROVALS

GEOPRESSURE ENERGY SYSTEM DIAGRAM
BLEACH PULP & PAPER MILL (TYP)

049-5005

Figure 7



MATERIAL BALANCE

PROCESS STREAM NUMBERS

	WOOD TO BARKING DRUM	GEOFLUID FROM WELL FIELD	GEOFLUID HYDRAULIC TURBINE OUTLET	VAPOR FROM FLASH VESSEL	BRINE FROM FLASH VESSEL	BARK & FINES TO BOILER	H.P. STEAM FROM BARK BOILER	BLACK LIQUOR TO RECOVERY BOILER	H.P. STEAM FROM RECOVERY BOILER	L.P. STEAM FROM TURBINE GENERATOR	BLEED STEAM TO DIGESTER
	1	2	3	4	5	6	7	8	9	10	11
FLOW (#/HR. x 10³)	247.67	3530.82	3530.82	167.700	3363.12	38.169	97.966	246.79	443.626	372.153	169.439
TEMPERATURE (°F.)	AMB.	250	246	200	200	AMB.	700	—	700	308	420
PRESSURE (PSIA)	—	2014.7	29.83	11.53	—	—	450	—	450	75	136
ENTHALPY (BTU/#)	—	222.87	214.42	1145.9	167.99	—	1359.9	—	1359.9	1181.9	1232.9
						4750(HHV)		4035(HHV)			

	L.P. STEAM TO PULP MILL	L.P. STEAM TO BLEACH PLANT	L.P. STEAM TO PAPER MILL	L.P. STEAM TO JET A	VAPOR TO JET A	L.P. STEAM TO JET B	VAPOR TO JET B	VAPOR TO JET C	BRINE FROM PRE-HEATER	BRINE FROM AIR PRE-HEATER	CONDEN-SATE RETURN
	12	13	14	15	16	17	18	19	20	21	22
FLOW (#/HR. x 10³)	120.767	18.466	169.813	6[illegible].107	62.059	82.721	33.090	72.552	1908.17	1454.95	541.592
TEMPERATURE (°F.)	308	308	305	308	200	308	200	200	135	133	280
PRESSURE (PSIA)	75	75	75	75	11.53	75	11.53	11.53	—	—	500
ENTHALPY (BTU/#)	1181.9	1181.9	1181.9	1181.9	1145.9	1181.9	1145.9	1145.9	102.9	100.90	249:49

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APPROVALS		DATE
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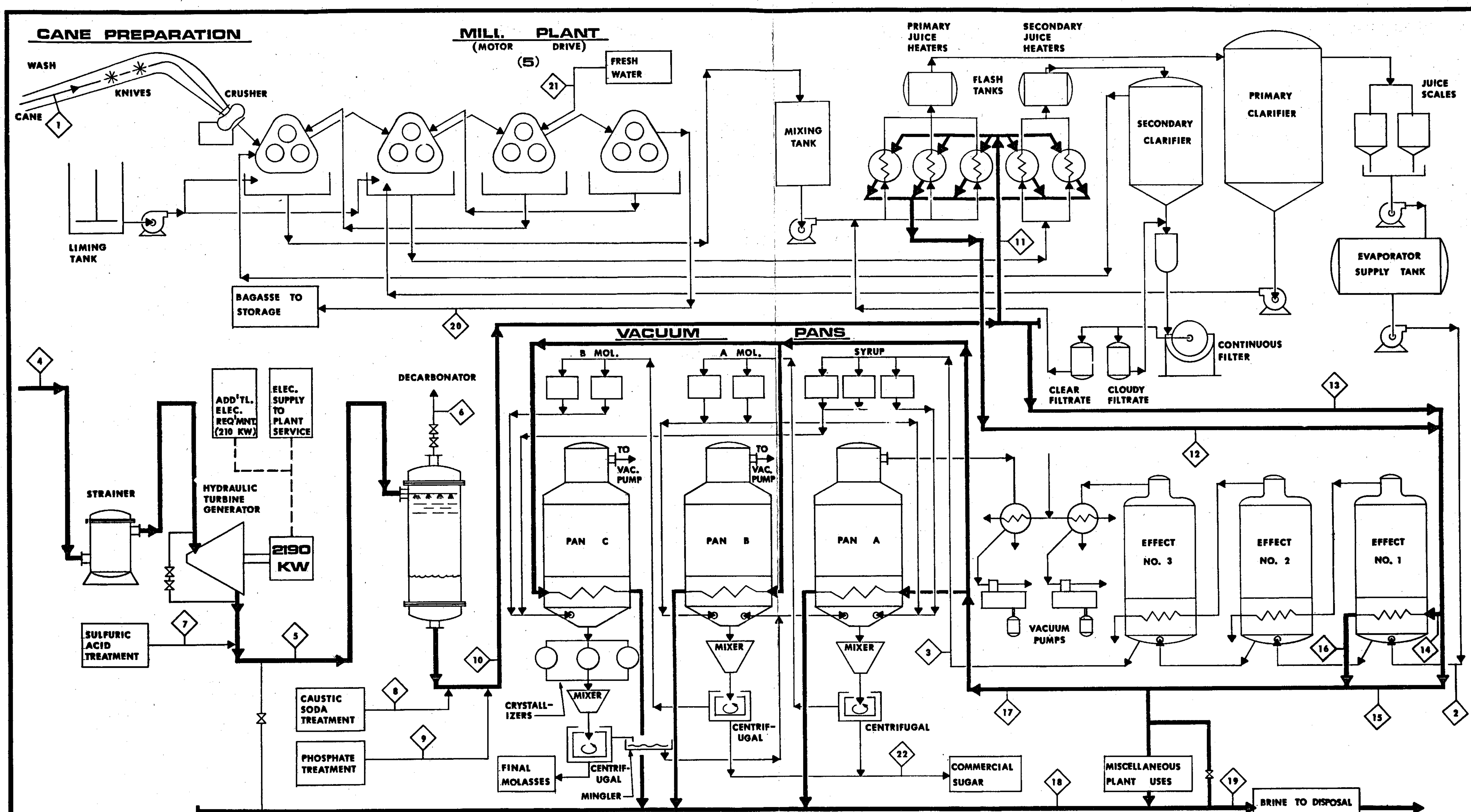
CHECKED	OJ MORIN	3/75
MECH		3/75
ELECT		
CIVIL		
PROJECT MANAGER		
P. E. REG. NO.		

TITLE: GEOPRESSURE ENERGY SYSTEM DIAGRAM
PULP & PAPER MILL(NEW)
DRAWING NO. 049-5006
REV.
SCALE
SHEET OF

Figure 8



MATERIAL BALANCE
PROCESS STREAM NUMBERS

	Cane to Mill Plant	Clarified Juice to Evaps.	Syrup to Pans	Geo. Fluid from Wells	Geo. Fluid to Decarb.	Carbon Dioxide Removed	Sulfuric Acid Feed	Caustic Soda Feed	Phosphate Feed	Geo. Fluid to Process	Geo. Fluid to Juice Heaters
	1	2	3	4	5	6	7	8	9	10	11
FLOW (#/HR. x10³)	200.00	212.00	48.760	1368.0	1368.0	0.0985	0.110	0.180	0.003	1368.0	962.308
TEMPERATURE (°F.)	AMB.	206	130	250	250	250	AMB.	AMB.	AMB.	250	250
PRESSURE (PSIA)	—	174.03	—	2014.7	50	—	—	—		50	50
ENTHALPY (BTU/#)	—		—	222.9	218.5	—	—	—		218.5	218.5
SPECIFIC GRAVITY	—						1.828				
BRIX	—	16	70				—				
PH	—			6.5	4.5		—			7.8	7.8

	Geo. Fluid from Juice Heaters	Juice Htr By-Pass Control	Geo. Fluid to Multi-Evaps.	Evap. By-Pass Control	Geo. Fluid from Evap.	Geo. Fluid to Pans	Geo. Fluid from Pans	Geo. Fluid to Disposal	Bagasse to Storage	Fresh Water to Process	Raw Sugar Product
	12	13	14	15	16	17	18	19	20	21	22
FLOW (#/HR. x10³)	962.308	405.700	1231.00	137.00	1,231.00	814.00	814.00	1368.0	48.00	60.00	16.960
TEMPERATURE (°F.)	224	250	232	232	193	197	155	163	100	AMB.	
PRESSURE (PSIA)	45	45	45	40	35	35	30	30			
ENTHALPY (BTU/#)	192.17	218.5	200.25	200.25	160.96	164.98	122.89	130.89	4273 (HHV)		
SPECIFIC GRAVITY											
BRIX											
PH											

PLANT SIZE:
100 TONS/HR. (CANE)

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APPROVALS		DATE
DRAWN	DK	3/75
CHECKED	OJ MORIN	3/75
MECH.	OJ Morin	3/75
ELECT		
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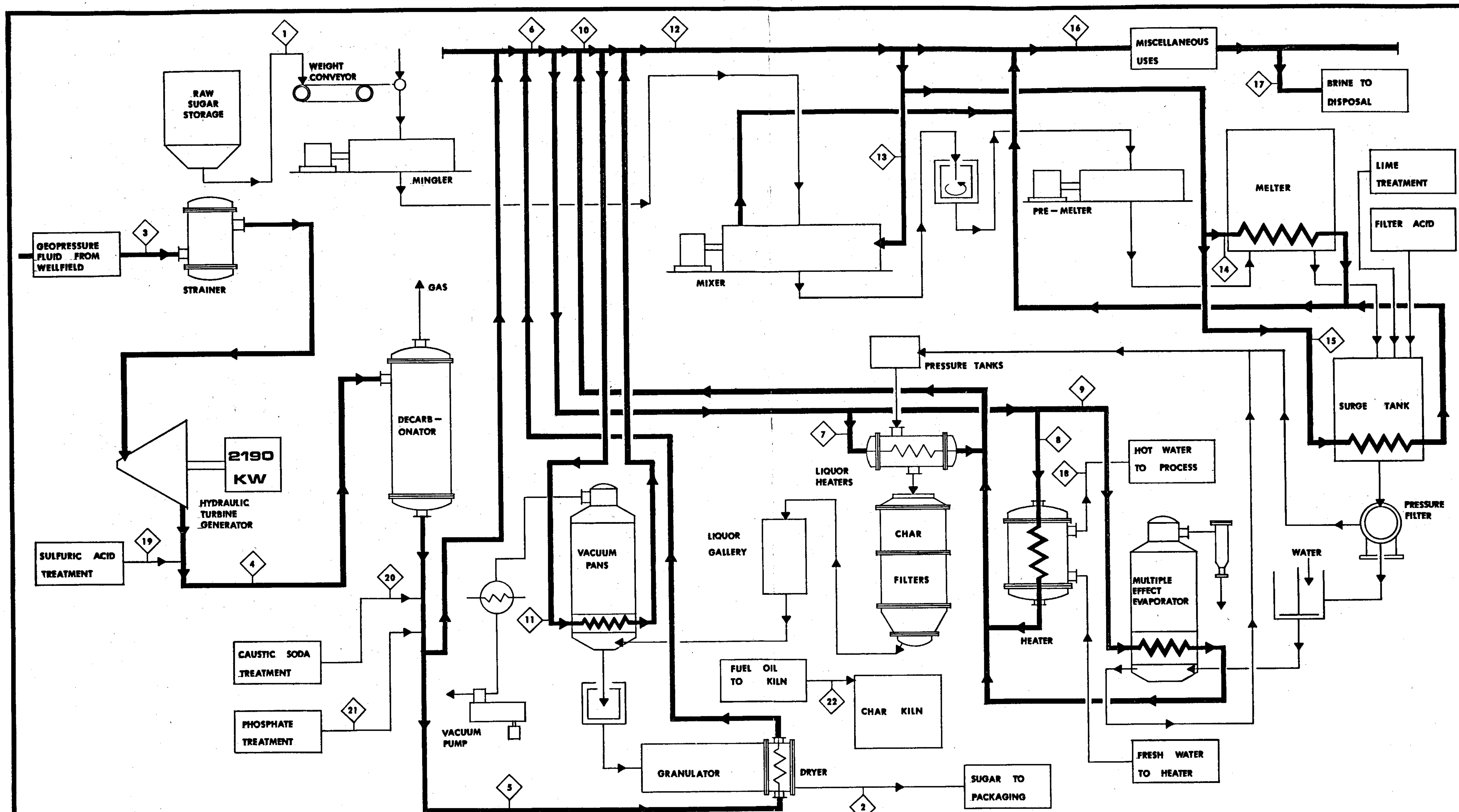
PROJECT MANAGER: [signature]
P. E. REG. NO.

TITLE: FLOW DIAGRAM GEOPRESSURE HEAT SOURCE
RAW SUGAR MANUFACTURE

DRAWING NO. 049-5009 REV.
SCALE SHEET OF

Figure 9



MATERIAL BALANCE — PROCESS STREAM NUMBERS	RAW SUGAR TO PROCESS	SUGAR TO PACKAGING	GEO. FLUID FROM WELL FIELD	GEO. FLUID TO PROCESS	BRINE TO DRYER	BRINE FROM DRYER	BRINE TO LIQUOR HEATER	BRINE TO HEATER	BRINE TO MULTI EFFECT EVAP.	BRINE FROM HEATERS & EVAP.	BRINE TO VACUUM PANS	BRINE FROM VACUUM PANS	BRINE TO MIXER	BRINE TO MELTER	BRINE TO SURGE TANK	BRINE TO MISC.	BRINE TO DISPOSAL	HOT WATER TO WASH & CENTRIF.	ACID FEED	CAUSTIC FEED	PHOSPHATE FEED	FUEL OIL TO KILN
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
FLOW (#/HR. x10³)	88.625	83.333	1368.00	1368.00	838.00	1368.00	76.645	241.778	495.140	1368.00	1352.32	1368.00	100.051	51.333	1201.00	1368.00	1368.00	98.908	0.110	.180	0.003	1.014
TEMPERATURE (°F)	AMB.	AMB.	250	250	250	235	235	235	235	207	207	169	169	169	169	161	153.8	180	AMB.	AMB.	AMB.	
PRESSURE (PSIA)			2014.7	50	50	45	45	45	45	40	40	35	35	35	35	30	25					
ENTHALPY (BTU/#)			222.9	218.5	218.5	203.00	203.00	203.00	203.00	175.52	175.52	136.9	136.9	136.9	136.9	128.6	121.69	147.92				
																						18,500 (HHV)

PLANT SIZE: 1000 TONS/DAY

DSS ENGINEERS, Inc.
FORT LAUDERDALE, FLORIDA

APPROVALS

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MECH	[illegible]	3/75
ELECT		
CIVIL		

PROJECT MANAGER [illegible]
P. E. REG. NO.

TITLE
FLOW DIAGRAM GEOPRESSURE HEAT SOURCE
SUGAR REFINERY (NEW)

DRAWING NO. 049-5012
REV.
SCALE
SHEET OF

Figure 10

For a new mill designed to use geothermal energy, the modifications are similar to those for an existing mill but are more extensive, so that additional geothermal heat can be extracted and one power boiler can be deleted. A diagram for the energy system of this plant is shown in figure 8. With this arrangement, gross energy needed from fuel and purchased electricity is reduced by 31.08 percent. This results in a fuel-oil savings of 595,634 barrels per year plus 85,256 tons per year savings in bark burned.

The existing mill studied is owned and operated by Boise-Southern Company and is the same capacity (1,000 tons per day) and general design as the typical mill. However, there were a number of variations and modifications which made geothermal utilization less attractive than for the typical plant. For this plant it is possible to reduce the gross energy requirement needed from

TABLE 1

Summary of Energy Data
Specific Cases in Pulp and Paper Industry

Case No.	I	II	III
Description	Typical Mill	New Mill	Boise-Southern Mill
Base without Geothermal			
(1) Gross Heat Input MMBtu's	12,804,120	12,804,120	12,112,299
(2) Fuel, Fuel Oil, bbl	595,634	595,634	673,770
(3) Fuel, Natural Gas, MCF	-0-	-0-	-0-
(4) Fuel, Bark and Fines, tons	219,000	219,000	131,400
(5) Purchased Electricity, 1,000 kwhr	-0-	-0-	280,320
Cases Studies			
(1) Gross Fuel Input, MMBtu's	10,322,496	8,249,180	9,511,040
(2) Geothermal-Heat Input, MMBtu's	1,520,673	2,703,525	906,114
(3) Fuel, Fuel Oil, bbl	200,937	-0-	420,140
(4) Fuel, Natural Gas, MCF	-0-	-0-	-0-
(5) Fuel, Bark and Fines, tons	219,000	133,744	131,400
(6) Purchased Electricity, 1,000 kwhr	46,498	54,760	305,689
(7) Geothermal Fluid, bbl/day	137,370	242,112	162,562
(8) Geothermal Fluid, Mbbl	40,112	70,697	47,468
(9) Gross Fuel Savings, MMBtu's	2,481,600	4,554,940	1,528,550
(10) Gross Fuel Savings:			
(a) Barrels Fuel Oil	394,697	595,634	248,495
(b) MCF, Natural Gas	-0-	-0-	-0-
(c) Tons Bark and Fines	-0-	85,256	-0-
(11) Gross Energy Reduction Plus Geothermal:			
(a) Millions of Btu's	1,993,371	3,979,960	1,262,175
(b) Percentage of Base	15.56%	31.08%	8.38%

Notes: Annual usage of requirements given; operation is 292 days (24 hours per day) per year.

fuel and purchased electricity by 8.38 percent. This results in reducing the fuel-oil consumption by 248,495 barrels per year but increases the purchased electricity. Again, part or all of this may be generated from the fluid-pressure energy.

A summary of the significant energy-use data and energy-savings data for each of the cases studied in the pulp and paper industry is given in table 1. The quantities given (except barrels per day for geothermal fluid) are annual usage. This is based on plant operation 292 days per year, 24 hours per day. Item 9 is the gross annual fuel savings in millions of Btus.

Cane Sugar Industry

The typical raw sugar mill studied has a capacity of 100 tons per day of sugar cane. The typical sugar refinery studied has a capacity of 1,000 tons per day of refined sugar.

The typical raw sugar mill (without geothermal) requires a gross energy input of 205.1×10^6 Btus/hr of process heat, or 443,024 million Btus per year. This is supplied from 51,840 tons of bagasse.

For geothermal use in an existing mill, some equipment must be added and the steam turbine-generator is no longer needed. The gross energy input from fuel and purchased electricity is reduced by 57 percent. This reduces the amount of bagasse burned by 32,616 tons per year, but 1200 kw of electricity must be purchased. This can be generated from the fluid-pressure energy.

For a raw sugar mill specifically designed to use geothermal energy the changes from a conventional mill are more extensive. The conventional fuel-fired power boiler and steam turbine generator are deleted, geothermal-fluid pretreating facilities are added, mill drives have electric motors, heat exchangers are designed for liquid-liquid heat exchange, and vacuum pumps are used in lieu of steam-ejector equipment. The process diagram for such a new raw sugar mill is presented in figure 9. This also shows the energy-supply and energy-utilization system employed.

With this system all process heat required is supplied directly by the geothermal fluid. Purchased electricity is increased by 2,400 kw or $5,184 \times 10^3$ kwhrs per year. The gross energy required from fuel plus purchased electricity is reduced by 88 percent. This saves all the bagasse produced which is 51,840 tons per year.

The modifications needed for existing and new sugar refineries to utilize geothermal energy are similar to those for raw sugar mills. The gross energy required from fuel plus purchased electricity is reduced by 37 percent and 80 percent for existing and new sugar refineries, respectively. This reduces the fuel-oil consumption by 85,762 and 832,156 barrels per year, respectively, but in a new sugar refinery $15,417 \times 10^3$ kwhrs/year of electricity would have to be purchased. This can be generated from the fluid-pressure energy. The process flow diagram for a new sugar refinery designed to use geothermal energy is shown in figure 10.

The existing sugar refinery studied is owned and operated by the South Coast Corporation. The overall design is similar to the typical refinery studied except the capacity is 600 tons per day. To use geothermal energy, some existing steam heaters should be replaced with liquid-liquid heat exchangers, and additional preheaters must be added. With these modifications, the gross energy input from fuel is reduced about 27 percent. This would save 250,984 thousand cubic feet per year of natural gas.

A summary of the significant energy-use data and energy-savings data for each of the cases studied is given in table 2. The quantities given (except barrels per day for geothermal fluid) are annual usage. This is based on 90 days operation per year for raw sugar mills and 292 days operation per year for sugar refineries. Item 9 is the gross fuel savings in millions of Btus.

TABLE 2
Summary of Energy Data
Specific Cases in Sugar Manufacture

Case No.	IV	V	VI	VII	VIII
Description	Typical Raw Sugar Mill	New Raw Sugar Mill	Typical Sugar Refinery	New Sugar Refinery	Existing Sugar Refinery
Base without Geothermal					
(1) Gross Heat Input, MMBtu's	443,024	443,024	1,456,185	1,456,185	1,349,412
(2) Fuel, Bagasse, tons	51,840	51,840	-0-	-0-	-0-
(3) Fuel, Fuel Oil, bbl	-0-	-0-	231,618	853,067	-0-
(4) Fuel, Natural Gas, MCF	-0-	-0-	-0-	-0-	1,303,780
(5) Purchased Electricity, kwhr	-0-	-0-	-0-	-0-	-0-
Cases Studied					
(1) Gross Fuel-Heat Input, MMBtu's	164,279	-0-	916,997	131,470	986,144
(2) Geothermal-Heat Input, MMBtu's	137,197	258,876	346,132	928,111	-0-
(3) Fuel, Bagasse, tons	19,224	-0-	-0-	-0-	-0-
(4) Fuel, Fuel Oil, bbl	-0-	-0-	145,856	20,911	-0-
(5) Fuel, Natural Gas, MCF	-0-	-0-	-0-	-0-	952,796
(6) Purchased Electricity, 1,000 kwhr	2,592	5,184	-0-	15,417	-0-
(7) Geothermal Fluid, bbl/day	93,806	93,806	93,806	93,806	19,680
(8) Geothermal Fluid, Mbbl/yr	8,443	8,443	27,391	27,391	5,746
(9) Gross Fuel Savings MMBtu's	278,745	443,024	539,188	1,324,715	363,268
(10) Gross Fuel Savings					
a. Tons Bagasse	32,616	51,840	-0-	-0-	-0-
b. Barrels Fuel Oil	-0-	-0-	86,762	832,156	-0-
c. MCF Natural Gas	-0-	-0-	-0-	-0-	350,984

Note: Annual usage or requirements given; raw sugar mills operating 90 days (24 hrs per day) per year; refineries operating 292 days (24 hr days) per year.

ECONOMICS

Basis

Capital costs were estimated based on mid-1974 costs. Estimating capital costs of energy-recovery equipment as well as new plant equipment was done by scaling costs of analogous plant equipment from the chemical industry, from other geothermal plants, and from the electric power industry. Standard estimating data and techniques were utilized.

Costs of waste-reinjection wells and equipment have been estimated, based on data in the Office of Saline Water Report No. 456 (Dow Chemical Company, 1969) and the Desalting Handbook for Planners (1972). Costs of supply wells were based on information obtained form Lawrence Livermore Laboratory and from Durham (1974).

All new or modified equipment is amoritized over 20 years at 8 percent interest. Including taxes and insurance, the fixed annual capital-cost charge is 11.81 percent. No analysis was made considering royalties, depletion allowance, or income taxes. System operation and maintenance costs were included, in most cases, at 5 percent of the initial capital costs per year.

Geoenergy-Fluid Supply and Disposal

A typical geoenergy fluid-supply well 13,000 feet deep is estimated to cost $2,100,000. This is for the well only, and the surface facilities required would cost about 10 percent of that, or $210,000, for a total capital cost of $2,310,000. The estimated average costs of supply wells of various depths is given in figure 11.

The unit costs of the geoenergy fluid at the surface varies proportionally to the cost of the supply well. We estimated production costs at 3.2¢/barrel for a 13,000-foot well to 7.5¢/barrel for a 18,000-foot well. This is shown in figure 12.

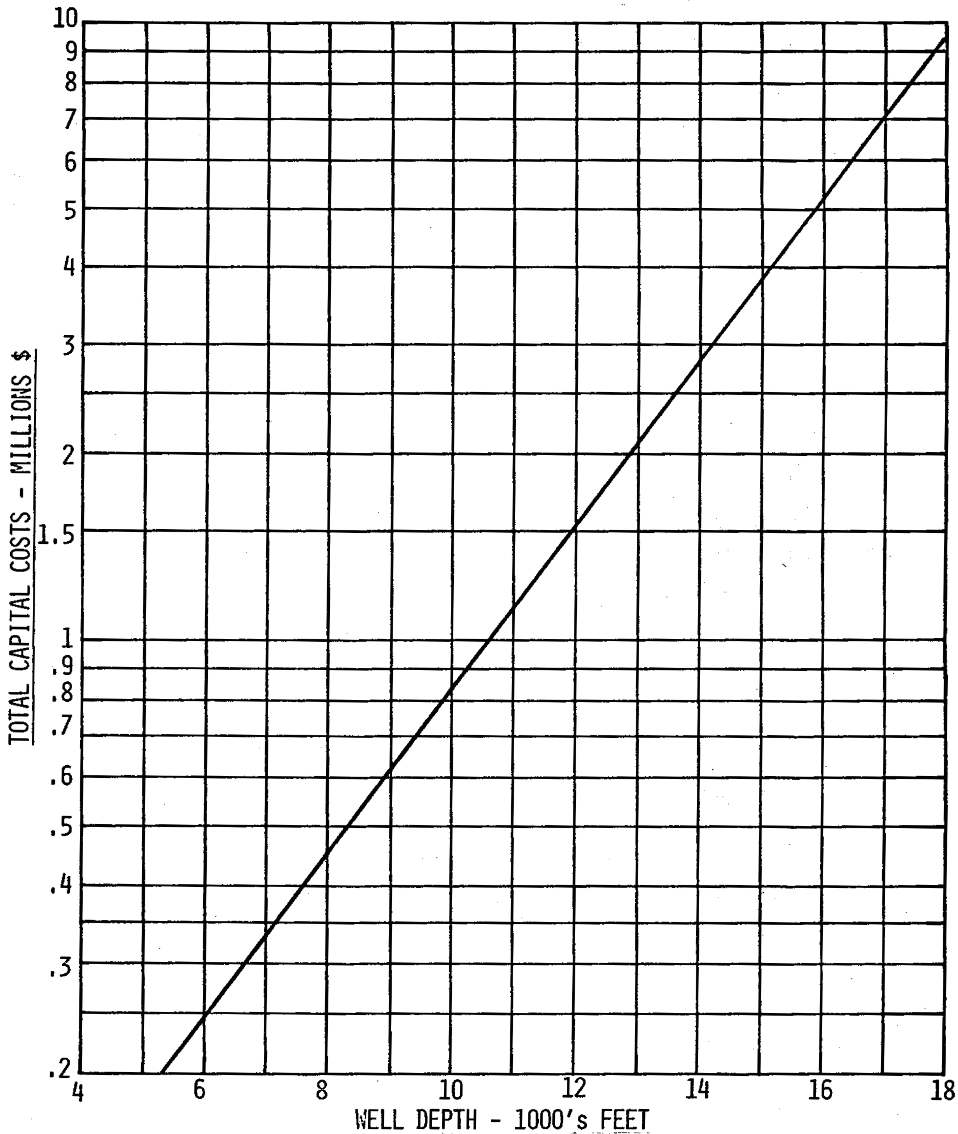

Figure 11. Well Supply Capital Cost as a Function of Well Depth.

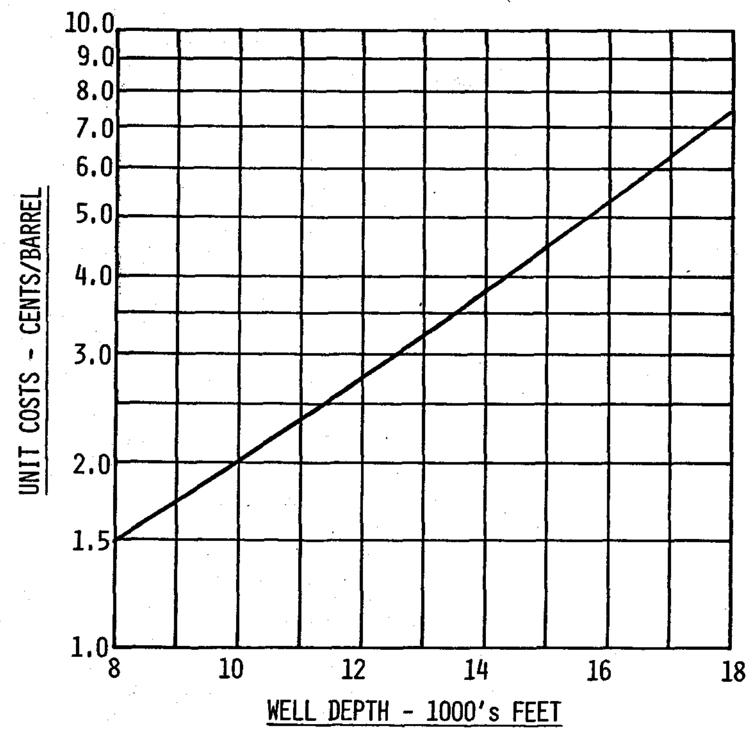

Figure 12. Supply Well Unit Production Costs as a Function of Well Depth, Annual Costs at 80 Percent Full Utilization.

The capital costs of waste-disposal wells and related surface equipment for 40,000 barrels per day were estimated at $600,000. Costs of injection facilities vs. injection capacity is shown in figure 13. The corresponding unit disposal costs are about 1¢/barrel.

Fuel- and Pressure-Energy Recovery

The capital costs of gas separators is relatively small. However, the cost for equipment to dehydrate, cool and purify the separated gas is significant. Others (Dow Chemical Company, 1974), estimated equipment at $941,000 to process gas from 262,000 barrels per day of fluid. Based on this, the unit costs to process the gas for use would be $.05 to $.10 per thousand cubic feet.

Installed capital costs for hydraulic turbines with generators are in the order of $230 to $290 per kw. Production costs are about 0.5¢/kwhr.

Total Systems Costs

The total capital costs for a typical fluid-supply, disposal, and energy-recovery system (without thermal-energy recovery) is $3,285,000. This is for a well 13,000 feet deep producing 40,000 barrels per day. The breakdown of this capital cost and the costs for systems with wells of other depths follows.

Well Depth, feet	8,500	13,000	16,000	18,000
Flow Rate, bbl/day	20,000	40,000	60,000	80,000
Fluid-Supply System	$583,000	$2,300,000	$5,610,000	$10,450,000
Fluid-Disposal System	340,000	600,000	880,000	1,140,000
Gas Separation and Purification	48,400	145,000	294,000	484,000
Electric Generation	60,000	240,000	330,000	410,000
Total Capital Costs	$1,031,400	3,285,000	7,114,000	12,484,000

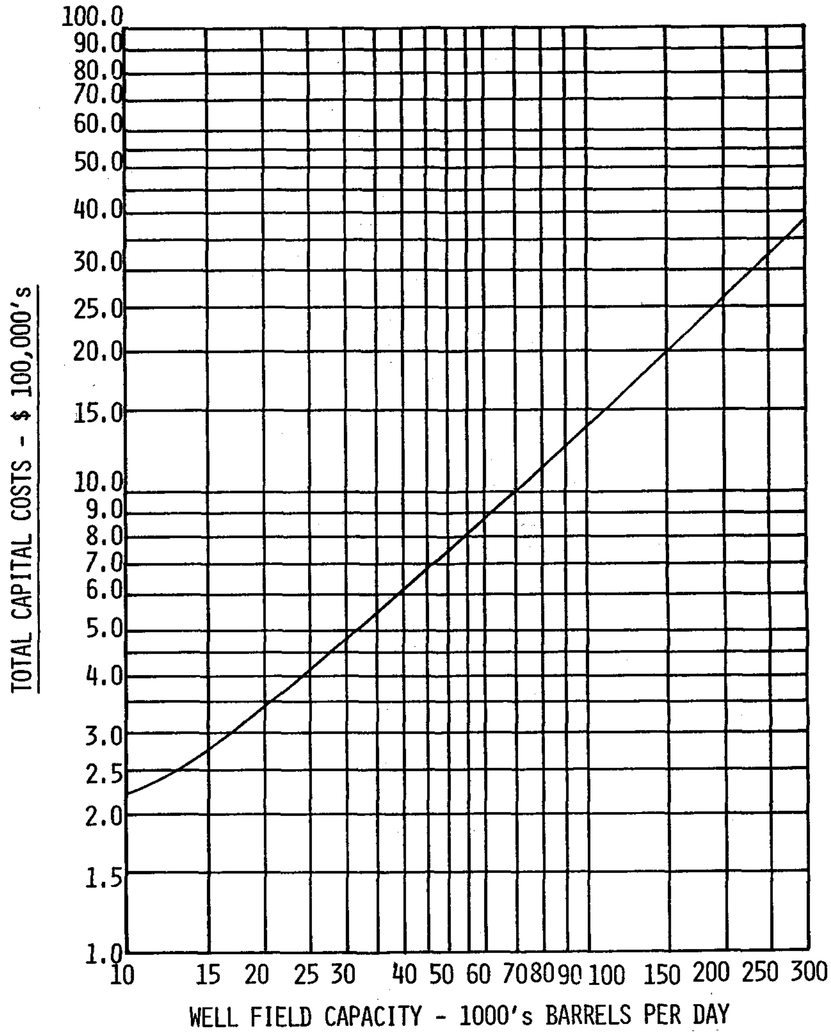

Figure 13. Cost of Injection Well Fields as a Function of Injection Capacity, Includes Surface Equipment.

Unit costs of geothermal fluid less credits for gas recovered and electricity generated from pressure energy is 0.89¢/barrel for a system with 18,000-foot-deep wells producing 350°F fluid discharge up to 5.79¢/barrel for 140°F fluid discharge. This is shown in table 3. These give rates of return on total capital of 15 percent up to 27 percent before taxes.

Thermal Utilization

PULP AND PAPER MILLS. For each of the cases studied in the pulp and paper industry, capital costs of new and modified equipment for thermal-energy extraction were estimated. Then, a value per barrel for the geothermal fluid was determined by dividing the annual net fuel savings (at $1.00 per million Btus) by the barrels per year of geothermal fluid required. This is shown in table 4. Assuming that the value per barrel of fluid for thermal energy is paid or transferred in credit to a geoenergy-operating system, the profit in excess of the 8 percent opportunity cost of capital included as costs can be calculated. From this, the overall rate of return on the capital can be calculated.

The capital costs for the fluid-supply system are assumed to be multiples of the number of wells required times the costs for a single-well system. Other unit capital costs are decreased on an exponential basis as capacity increases. However, to simplify the economic analysis, the credits for gas and electricity are not increased with production. This is considered conservative.

The capital costs and returns for the cases studied are given in table 5. The overall rates of return before taxes range from 14.7 percent to almost 26 percent.

CANE SUGAR INDUSTRY. The procedure and basis for the economic analysis of geoenergy use in this industry is essentially the same as for the pulp and paper industry. However, for raw sugar mills, operation is assumed to be only 90 days per year instead of 292 days per year. Thus, thermal utilization for raw sugar mills would be 90 days a year, but gas recovery and electrical generation would still be obtained 292 days per year.

The costs and unit values of geoenergy-fluid calculated for each case studied are given in table 6. The raw sugar mills, cases IV and V, use the geothermal fluid at the rate of 93,806 barrels per day only 90 days of the year. Hence, the annual payment or credit for this is quite low. Also, the existing refinery, case bviii, uses only 19,680 barrels per day of the 40,000 barrels per day of fluid available. If this refinery was twice as big, full use would be realized, and the annual payment or credit would double.

TABLE 3

Geoenergy Systems
Operating Costs and Credits

Well Depth, feet	8,500	13,000	16,000	18,000
Flow Rate, bbl/day	20,000	40,000	60,000	80,000
Fluid Temperature, °F	200	250	300	350
Gas Content, Scf/bbl	20	30	40	50
Surface Pressure, psi	1,000	2,000	3,000	4,000
Capital Costs, $	1,031,400	3,285,000	7,114,000	12,484,000
Fluid Supply, ¢/bbl	1.70	3.20	5.30	7.50
Fluid Disposal, ¢/bbl	1.10	1.00	0.98	0.96
Gas Credit, ¢/bbl	(1.87)	(2.81)	(3.74)	(4.68)
Electric Credit, ¢/bbl	(0.12)	(0.50)	(0.50)	(0.50)
Net Cost, ¢/bbl	0.81	0.89	2.04	3.28
Thermal Value, ¢/bbl at $1.50 per MMBtu extracted				
(1) 200°F discharge	0	2.63	5.25	7.88
(2) 180°F discharge	1.05	3.68	6.30	8.93
(3) 160°F discharge	2.10	4.73	7.35	9.98
(4) 140°F discharge	3.16	5.79	8.42	11.05

Basis:
(1) Interest Rate 8 Percent, Life 20 Years.
(2) Utilization or Load Factor = 80 Percent.
(3) Gas Value = $1.035/Mft^3, Extraction and Purification = $.10/Mft^3.
(4) Electric Value = 1.5¢/kwhr, Generation Costs = 0.5¢/kwhr.
(5) Thermal = $1.50 per 10^{6}Btu extracted, Net Value.

Table 7 gives total energy-system capital costs; operating costs and credits, and overall rates of return for each of the cases studied. For cases IV, V, and VII, the thermal-utilization factor is lower than that for extracting gas and generating electricity from the geoenergy fluid. This is the main reason for the low rates of return in these cases. For instance, if the existing refinery studied was doubled in size, it would fully utilize the available geothermal fluid and the overall rate of return would increase to about 23 percent.

CONCLUSIONS

The overall conclusion of the study is that utilization of thermal energy from the geoenergy fluid in pulp and paper mills and new sugar refineries is technically sound and economically viable, provided that the other energy in the fluid (natural gas and pressure) is recovered concurrently.

Studies on specific sites and plants are needed to refine and verify the information developed in the general study. Geological exploration is needed to provide more exact data on the nature and extent of the geoenergy resource.

TABLE 4

Geothermal Utilization Costs
Pulp and Paper

Case No.	I	II	III
Description	Typical Mill	New Mill	Boise-Southern Mill
(1) Flash Vessel	$ 64,399	$ 113,498	$ 64,399
(2) Pretreatment	43,935	40,000	43,935
(3) Wash-Water Heater	148,060	148,060	-0-
(4) Final-Wash Heater	63,194	63,194	-0-
(5) Jet Compressors	20,000	30,000	20,000
(6) Waste-Discharge Pumps	27,985	43,053	27,984
(7) Dryer-Preheater	-0-	-0-	-0-
(8) Boiler M-U Heater	-0-	-0-	86,869
(9) Delete Boiler	-0-	(452,100)	-0-
Total Capital Costs	$367,572	$ 135,705	$ 243,187
Gross Fuel-Cost Saving	$2,719,640	$4,311,703	$1,515,543
Annual Costs	61,789	22,812	40,880
Extra Purchased Electricity Cost*	697,470	821,200	380,500
Net Annual Fuel Saving	$1,960,381	$3,467,691	$1,094,163
Barrels per day Required	137,370	242,112	162,562
Barrels per year Required	40.120×10^6	70.697×10^6	47.468×10^6
Value per Barrel	4.886¢	4.905¢	2.310¢

*Includes that supplied by geopressured electric generation

TABLE 5

Geoenergy System—Pulp and Paper
Capital Costs and Rates of Return

Case No.	I	II	III
Description	Typical Mill	New Mill	Boise-Southern Mill
Capital Costs			
(1) Fluid Supply	$ 6,900,000	$ 13,800,000	$ 9,200,000
(2) Fluid Disposal	1,850,000	3,800,000	2,300,000
(3) Gas Separation and Purification	420,000	840,000	560,000
(4) Electric Generation	600,000	1,100,000	800,000
(5) Thermal Extraction	367,600	135,700	243,200
Total System Cost	$10,137,600	$19,675,700	$13,103,200
Costs and Credits, ¢/bbl			
(1) Fluid Supply	3.20	3.20	3.20
(2) Disposal	0.90	0.86	0.90
(3) Gas Credit	2.81	2.81	2.81
(4) Electric Credit	0.50	0.50	0.50
(5) Thermal Credit	4.89	4.91	2.31
Net Return, ¢/bbl	4.08	4.16	1.52
Barrels per Year	40.12×10^6	70.70×10^6	47.47×10^6
Annual Return*	$ 1,636,900	$ 2,937,460	$ 721,544
Overall Cap. Rec. Factor	0.2612	0.2566	0.1569
Overall Rate of Return	25.8%	25.4%	14.7%

*Return in excess of opportunity cost of capital of 8 percent.

TABLE 6

Geothermal Utilization Costs
Cane Sugar Industry

Case No.	IV	V	VI	VII	VIII
Description	Typical Raw Sugar Mill	New Raw Sugar Mill	Typical Sugar Refinery	New Sugar Refinery	Existing Sugar Refinery
Capital Costs					
(1) Flash Vessel	$ 43,972	-0-	$ 43,972	-0-	-0-
(2) Jet Compressors	30,000	-0-	-0-	-0-	-0-
(3) Waste Pump(s)	19,360	-0-	19,360	-0-	-0-
(4) Chemical Treatment	-0-	85,000	30,000	85,000	28,000
(5) Vacuum Pumps	-0-	53,961	-0-	53,961	-0-
(6) Heat-Transfer Surface	-0-	180,972	31,589	207,532	85,898
(7) Mill-Motor Drives	-0-	103,670	-0-	-0-	-0-
(8) Enlarge Equipment	-0-	150,000	-0-	150,000	-0-
(9) Delete Equipment	-0-	(876,538)	-0-	(522,118)	-0-
Total Capital Costs	$ 93,332	$ (302,953)**	$ 124,921	($ 25,625)**	$ 113,898
Gross Fuel Savings	$ 195,696	$ 311,040	$ 539,188	$1,456,185	$ 350,348
Annual Extra Costs	15,609	(50,923)**	20,999	(4,308)**	19,146
Extra Purchased Electricity*	-0-	$ 77,760	-0-	$ 230,200	$46,570
Net Annual Savings (Annual Credit)	$ 180,087	$ 284,203	$ 518,184	$1,230,293	$ 331,202
Barrels per Day Required	93,806	93,806	93,806	93,806	19,680
Barrels per Year Required	8.443×10^6	8.443×10^6	27.391×10^6	27.391×10^6	5.747×10^6
Value per Barrel	2.133¢	3.366¢	1.892¢	4.492¢	5.763¢
Annual Credit to Energy Supply System	$ 180,087	$ 284,203	$ 518,184	$1,230,293	$ 331,202

*Includes that supplied by geopressured energy generation.
**Parentheses indicate savings.

TABLE 7

Geoenergy System—Cane Sugar Manufacture
Capital Costs and Rates of Return

Case No.	IV	V	VI	VII	VIII
Description	Typical Raw Sugar Mill	New Raw Sugar Mill	Typical Sugar Refinery	New Sugar Refinery	Existing Sugar Refinery
Capital Costs					
(1) Fluid Supply	$ 4,600,000	$ 4,600,000	$ 4,600,000	$ 4,600,000	$ 2,300,000
(2) Fluid Disposal	1,320,000	1,320,000	1,320,000	1,320,000	600,000
(3) Gas Separation and Purification	290,000	290,000	290,000	290,000	145,000
(4) Electric Generation	482,000	482,000	482,000	482,000	240,000
(5) Thermal Extraction	93,300	(302,900)	124,900	(25,600)	113,900
Total System Cost	$ 6,796,300	$ 6,400,100	$ 6,827,900	$ 6,677,400	$ 3,398,900
Costs and Credits, ¢/bbl					
(1) Fluid Supply	3.20	3.20	3.20	3.20	3.20
(2) Fluid Disposal	0.94	0.94	0.94	0.94	1.00
(3) Gas Credit	2.81	2.81	2.81	2.81	2.81
(4) Electric Credit	0.50	0.50	0.50	0.50	0.50
Net Unit Costs*					
Thermal Credit, ¢/bbl	0.83	0.83	0.83	0.83	0.89
Net Annual Costs before Thermal Credit	180,087	$ 284,203	$ 518,184	$ 1,230,293	$ 331,202
Annual Return**	(47,756)	56,846	290,892	1,003,058	226,182
Overall Cap. Rec. Factor	0.09490	0.10274	0.14445	0.25207	0.1684
Overall Rate of Return	7.6%	8.1%	13.2%	25.0%	15.9%

*Before thermal credit.
**Return in excess of opportunity cost of capital of 8 percent.

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Discussion

Hodges
Osborn-Hodges Engineering

Would you explain your disposal cost of 1¢ per barrel that you put out, I think, at about page 47 [preprint page number]?

Hornburg

Well, actually, the 1¢ a barrel is not a constant figure. It does go down from about 1.2¢, I believe, to something like 0.85¢, depending on how much material you're disposing of. But this was based on the average condition of the 300-foot well injecting 400 gallons per minute for each well.

If you had a storage tank and settling ponds, you would make sure that any of that iron or other solids were settled out and we would have pumps reinjecting at 200 psi pressure, and that's how we did it.

Shulman
Geothermal Power Co., Inc.

I notice you use a number of a dollar per million Btu's in your evaluation. It is true that if you use $2 a million Btu's, which would relate to $12 per barrel of oil cost, that your capital return would double to 40—to 45 percent?

Hornburg

Well, your capital return would go up. Whether it would quite double, I don't believe that's exactly correct. We had to use the figure of $1 per million Btu's. It was a nice even figure to use. We did a lot of sensitivity analyses on this, particularly with regard to depths of well temperatures and pressures from the wells, and it was amazing how high the rates of return could go up if you could just get the same—say 300° from a 10,000-foot well. You could get a 40 percent rate of return; something like this. Anybody can go through the sensitivity analyses, of course.

Shulman

All I'm submitting is that the $1 a million may be a low number in the coming years.

Hornburg

Yes, and the cost of capital might go up and the cost of wells may go up also.

Butler
Chevron Oil Company

I was curious about your well cost. I believe your slide, if I read that correctly, said an 18,000-foot well would cost $9.5 million. Is that correct?

Hornburg

That's pretty close to it, yes.

Butler

Where did you get those costs?

Hornburg

Offhand, I couldn't tell you; there were three or four different sources. Do you think that's high or low?

Butler

That's pretty high.

From the Floor

That's pretty low. (Laughter)

Hornburg

Well, we think they are on the conservative side. We think everything our figures show are on the conservative side. As I say, the economics, rate of return, is a little marginal, but everything else in the sensitivity analysis shows that rates of return would probably be much higher.

Bonnecarrere
State of Louisiana

I missed the depth of your disposal well. Did you say 300 feet? I don't know if that was 300 from the sand thickness or the depth of the disposal.

Hornburg

It's the depth from the surface. I think it was 300 feet. No, it's deeper than that. It is in the paper.

Mullican
Texas Water Quality Board

In reference to the depths of the disposal wells for injection, I rather doubt that you could find any place in Texas that would handle 40,000 barrels a day at that depth, and I rather doubt that the Water Quality Board or the Railroad Commission would allow this.

Hornburg

One well is not handling 40,000 barrels a day. One well is either 300 or 400 gpm. I don't know what it is, but there are a number of wells which would have to be drilled. I think three or four to handle 40,000 barrels a day at 200 psi.

Underhill

Do I interpret your statement as saying that it's not necessarily a question of one well, but it's a question that no reasonably small region would handle that much injection?

Mullican

Not really. The main problem would be the environmental aspect as to the protection of ground and surface water.
[In the open discussion period, Mr. Hornburg corrected a typographical error on the well depth in his preprint. The disposal well was to be 3,000 feet deep.]

Barnea

I would like to express my appreciation, but I have a number of questions on the economics. Mr. Shulman is right. The assumption of the $1 dollar per million Btu today is not realistic, but there is another assumption which is important for the economics.

Why is there an assumption of a total amortization for the power installation for 20 years? Is the amortization period based on the assumption of the well life, or what is the reason for the 20-year amortization. Now, if the amortization would be over 30 years and we could have one or more fields applying all this, economics would again be very much different.

Hornburg

You are correct, of course, that 30 years or even longer life would change the economics. We're not looking at electric-power generation here. It's only one little aspect and that is the hydraulic turbine that has to do with power generation. Our main concern is the life of the wells and the life of the reservoir.

We also then have thermal recovery in heat-exchanger equipment, which is commonly amortized over 20 years and not 30 or 40.

Barnea

But if you would start out with the availability of two fields of which the second one would be used, say, after 15 years and then you would allocate your amortization over the life of your equipment, your economics would be very much different.

Hornburg

I agree. There's a lot of things that could be done with these economics, which we hope, if anything is done, would make them look better. We didn't do a detailed economic analysis. We did what we thought would at least get the facts and figures so that others can juggle them the way they please to get what they want to get.
[Further discussion will be found in the open discussion period at the end of this session.]